Porcine trial validation of model-based cardiovascular monitoring of acute pulmonary embolism

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Introduction

Diagnosis and treatment of cardiac and circulatory dysfunction can be error-prone and relies heavily on clinical intuition and experience. Computer-based approaches utilising measurements available in the Intensive care unit (ICU) can provide a clearer physiological picture of a patient's cardiovascular status to assist medical staff with diagnosis and therapy decisions. **This research tests whether *in silico* subject-specific cardiovascular system (CVS) models, identified using only measurements available in the ICU, can track disease dependent changes in a porcine model of acute pulmonary embolism (APE).**

Methods Overview

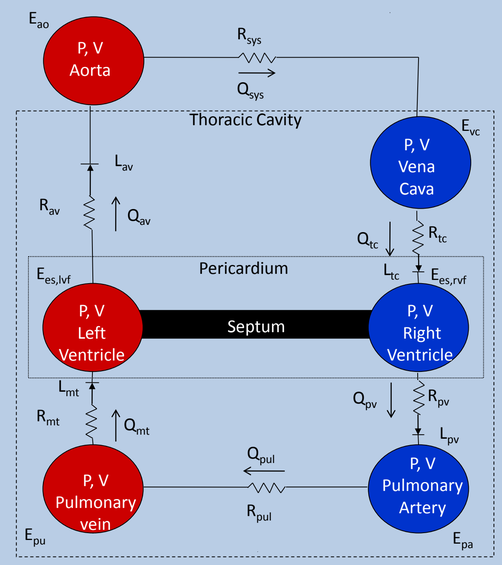
A computer CVS model is personalised to each subject via an identification process utilising measurements from porcine trials. In this process the CVS model acts a framework of cardiac and circulatory physiology to which hemodynamic parameters can be individualised to.

Porcine measurements + **CVS model** → **Subject-specific models**

CVS Model

Lumped parameter six chamber model representing the pressures, volumes, and flows across the CVS. Defined using parameters or resistance to flow and vascular elastance (stiffness). Features of the model include:

- Myocardium activation
- Valve dynamics
- Elastic chambers
- Ventricular interaction



Porcine Measurements

Subject-specific CVS models were identified in five pig trials. Autologous blood clots were inserted every two hours to simulate APE and continuous measurements were recorded every 30 minutes of:

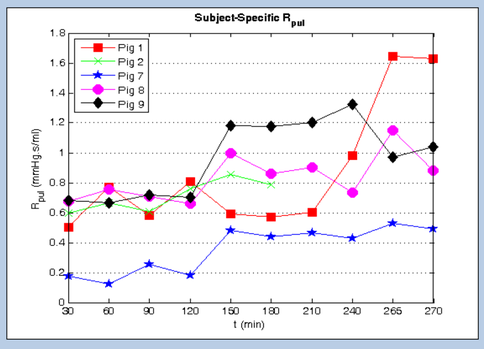
- Aortic and pulmonary artery pressures (P_{ao}, P_{pa})
- Left and right ventricular volumes (V_{lv}, V_{rv})
- Left and right ventricular pressures (P_{lv}, P_{rv})

P_{ao} and P_{pa} were used to identify the CVS model while V_{lv}, V_{rv}, P_{lv}, and P_{rv} waveforms were only used to validate the accuracy of the model outputs.

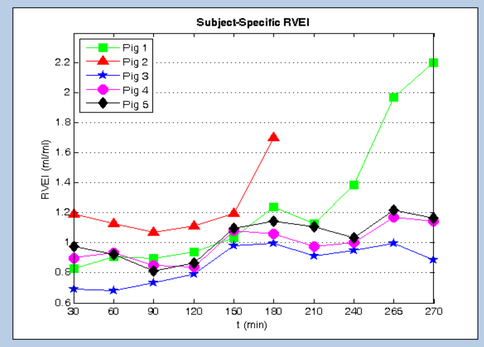
Detecting Pulmonary Embolism

The following trends, indicative of APE, were observed by the CVS models:

- Increased pulmonary vascular resistance ➔ R=0.68 with experimentally calculated metric
- Increased right ventricular contractility
- A sharp drop in systemic resistance near death
- Increased RVEI (RVEDV/LVEDV) ➔ R=0.88 with measurements from the porcine trials



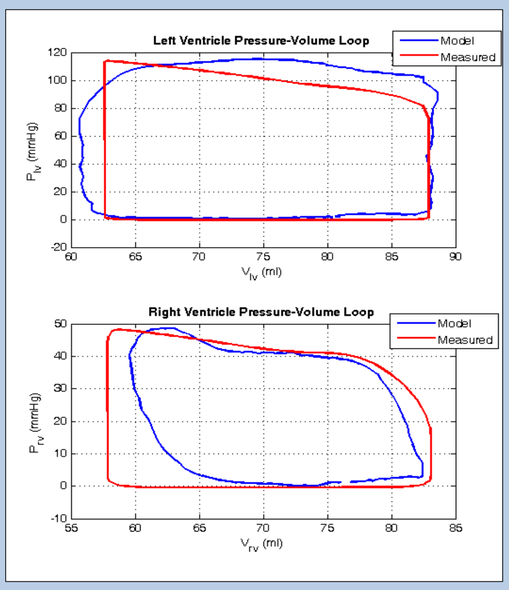
Systemic vascular resistance



RVEDV/LVEDV

Validating the Subject-Specific Models

For validation, outputs of the subject specific models were compared to measurements from the porcine trials that were not used in the identification process, such as the ventricular pressure and volume waveforms. The model matched the maximum ventricular pressures and mean ventricular volumes to average absolute errors of 4.3% and 4.4% respectively which is less than the measurement noise of the experiment (~10%).



Right and left ventricular pressure-volume loops

Conclusions

Personalised computer models of the CVS are capable of tracking disease dependent hemodynamic changes and monitoring the effectiveness of treatment in a porcine model of acute pulmonary embolism. Furthermore, the method…

- Has the potential to run in real time for **continuous monitoring**
- Is **cheap and easy to implement** as it only utilises equipment and measurements already available in the ICU
- Accurately estimates important CVS like **preload** (LVEDV, RVEDV), **aftreload** (systemic and pulmonary resistance and stiffness), **inotropy** (left and right ventricular end systolic elastance).

These results suggest their may potential benefits in using computer models of the CVS to assist medical staff with diagnostic and therapeutical decisions.